NISAR Spacecraft Concept Overview: Design challenges for a proposed flagship dual-frequency SAR Mission

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Abstract— **NISAR would be the inaugural collaboration between National Aeronautics and Space Administration (NASA) and Indian Space Research Organization (ISRO) on an Earth Science mission, which would feature an L-Band SAR instrument and an S-Band SAR instrument. As partners, NASA and ISRO would each contribute different engineering elements to help achieve the proposed scientific objectives of the mission. ISRO-Vikram Sarabhai Space Centre would provide the GSLV-Mark II launch vehicle, which would deliver the spacecraft into the desired orbit. ISRO-Satellite Centre would provide the spacecraft based on its I3K structural bus, a commonly used platform for ISRO's communication satellite missions, which would provide the resources necessary to operate the science payload. NASA would augment the spacecraft capabilities with engineering payload systems to help store, and transmit the large volume of science data.**

The combination of two SAR instruments on one platform would challenge the capabilities of both ISRO and NASA. The following are some of the challenges that will be discussed in the paper. The desire to operate both radars simultaneously would lead to a several-kilowatt power system design. The need to point the radar antenna to within a tenth of a degree would drive the attitude control system design. At peak rates, each instrument would produce data at gigabit per second speeds, which would drive the data transfer and storage capabilities. Furthermore, these data volumes would require the transition from an X-Band telecommunication system to Ka-Band, which could support multi-gigabit data rates.

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1. Introduction

NASA-ISRO Synthetic Aperture Radar (NISAR) is a proposed joint mission between the United States and India that would launch in 2020. This would be the first dual-frequency (L- & S-Band) space-based SAR mission to monitor the changes in the earth system over a period of three years and ISRO has specified the mission life of the spacecraft as five years. This flagship partnership would have major contributions from both agencies. NASA would be responsible for providing the L-Band SAR payload system in which the ISRO supplied S-Band SAR payload would be integrated to define the complete science payload. In addition, NASA would provide engineering payloads for the mission, including a Payload Data Subsystem, High-rate Science Downlink System, GPS receivers and a Solid State Recorder. ISRO is responsible for providing the spacecraft bus systems and the GSLV-Mk II launch system and associated services.

This partnership has been nurtured over the last three years, and presently is in Phase A with the transition to Phase B expected in early 2015. The two agencies have recently signed the Implementing Arrangement, clarifying the roles each organization would perform for the NISAR mission.

This paper provides an overview of the concept development and some of the major spacecraft, engineering payload, and launch vehicle design challenges the JPL and ISRO project teams would face. Figure 1 shows the in-orbit NISAR Observatory configuration.

2. Science and Instrument Overview

Science Overview

The primary science objective of the NISAR mission would be to measure changes in the land and ice-covered surfaces of the planet, relating them to climate and natural hazards. NISAR science is inspired by the objectives of the DESDynI mission concept, first identified in the National Academy of Sciences' Decadal Survey Report from 2007. NISAR would use repeat pass interferometry to provide centimeter-scale observations for the Solid Earth and Ice Dynamics science communities. The repeat pass Interferometric SAR (InSAR) technique would allow scientists to detect changes in the surface of the Earth by interferometrically combining two separate images of the same area, obtained at different times. NISAR would study ecosystems, notably biomass and disturbance of forests, agricultural areas and wetlands, by exploiting the NISAR

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radar's capability to transmit and receive different polarizations.

The proposed NISAR mission would be conducted from a 12-day, exact repeating orbit, with an index altitude of 747 km. Over the course of the 12-day cycle, the Earth would be systematically mapped, based on the availability of system resources for acquiring, storing, and transmitting the data.

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Instrument Overview

NISAR would feature two instruments: an L-Band SAR instrument and an S-Band SAR instrument [2], which offers the opportunity to perform improved biomass estimation. NASA/JPL would provide the L-Band instrument, operating at a frequency of 1215-1300 MHz and ISRO would provide the S-Band instrument, which operates at 3100-3300 MHz. Both instruments would be collocated on the same radar instrument structure and would share a common 12-m parabolic reflector, mounted on a 9-m boom.

Both instruments would use repeat pass interferometry to detect centimeter-scale changes, and have the capability to transmit and receive different polarizations. In addition, both instruments would be the first to implement the SweepSAR technique, a scan-on-receive digital beam tracking approach, which allows for increased swath width.

3. Spacecraft Challenges

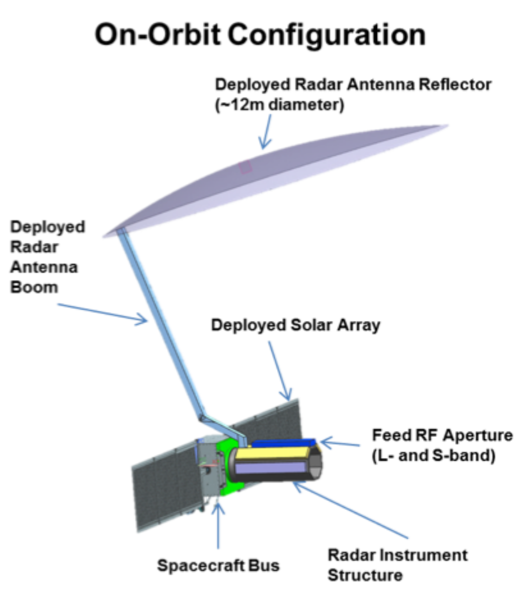

Figure 1 – Proposed NISAR Configuration

Spacecraft Overview

The spacecraft proposed for the NISAR mission is the I3K structure, which is commonly used on Indian GEOSAT missions as well as Indian communication satellites. The spacecraft features subsystems with significant flight heritage.

The spacecraft is a 3-axis stabilized spacecraft, with reaction wheels and torque rods for momentum management. Additional elements of the Attitude/Orbit Control Subsystem include star trackers, sun sensors, inertial reference units with accelerometers, and magnetometers.

The propulsion subsystem is a monopropellant blowdown system with a 390-liter tank that carries propellant for a mission life of 5 years. The spacecraft uses thirteen 11-Newton thrusters to perform maneuvers for controlling the spacecraft position and can also be used to control the spacecraft orientation.

The telecom subsystem includes an S-band telecom system for Telemetry, Tracking and Command (TT&C) and a Ka-Band telecom system for downlinking large amounts of science data to the ISRO ground station(s). The S-band system can support an uplink rate of 4 kilobits per second and a downlink rate of 16 kilobits per second. The Ka-band system can downlink data at a rate up to 1.2 Gigabits per second (Gbps). The ISRO telecom subsystem employs three antennas: two S-Band antennas and a deployable Ka-Band, 0.7 m diameter antenna.

The C&DH system includes the On Board Computer (OBC) and Baseband Data Handling (BDH) systems. The OBC handles command and control for spacecraft subsystems and provides associated subsystem telemetry; while BDH takes care of Payload Data Telemetry and routes the S-Band SAR high-rate data to the ISRO Ka-Band Telecom.

The key challenges for the spacecraft design are the structural design, attitude/orbit control and large volume of data handling.

Structural Accommodation of the Radar Payload

The primary requirements on the spacecraft bus structure are to meet the launch vehicle stiffness requirements and support the radar payloads. The challenge in building up the structure is the extended height of the payload and the mass. Close to three meters in length, and with a mass close to a metric ton, the spacecraft structure must be well designed to accommodate the payload.

The main spacecraft bus structure assembly, shown in Figure 2, consists of a central cylinder, shear webs, top deck, and bottom deck.

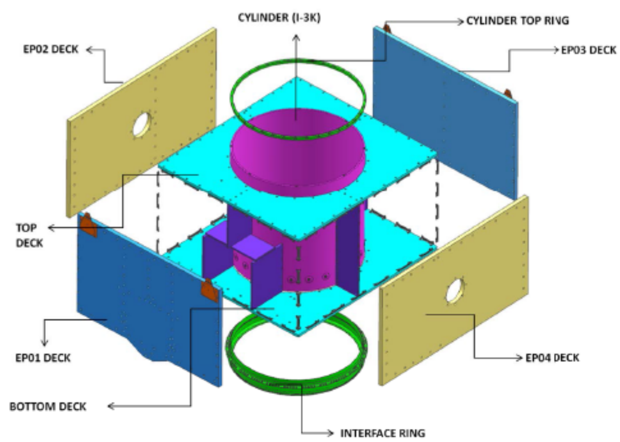

Figure 2 – ISRO I-3K Bus Structure

The central cylinder assembly has a nominal diameter of 1179 mm and consists of a carbon fiber reinforced polymer (CFRP) facesheets and aluminum honeycomb sandwich cylinder, launch vehicle interface ring, top deck ring and a cylinder top ring with structural interfaces for the NISAR payload. All the end rings are metallic and made of aluminum alloys. The CFRP sandwich cylinder is bonded and riveted to the aluminum interface ring and top ring with doublers and titanium/aluminum rivets.

There are six shear webs provided around the central cylinder. The shear webs are connected to the outside of the central cylinder using CFRP angles through a bonded and bolted/riveted joint. While three sides of the central cylinder have one shear web each, the +yaw side has three discontinuous shear webs. Two shear webs are provided from the bottom deck, which terminate at an intermediate deck at a height of 513 mm. A single shear web is provided from the intermediate deck onwards till the top deck. These discontinuous shear webs and the intermediate deck provide stiffness to the Dual Gimbal Antenna (DGA) assembly mounted on the outside of the +yaw panel of the main bus. The shear webs along the pitch are offset from the center by 157.7 mm to accommodate the Solar Array Drive Assembly (SADA) and to transfer the solar panel loads as well as provide stiffness to the solar array.

The bottom deck is mounted on the outer flange of the interface ring at 24 discrete locations.

The top deck is mounted at 24 locations on the outer flange of the top deck ring which is a T-ring bonded and riveted to the central cylinder.

Attitude/Orbit Control System Design

For NISAR to successfully perform repeat-pass interferometry, very precise knowledge and control of the spacecraft pointing would be required, as well as the ability to perform small maneuvers to maintain the spacecraft in the proper orbit. The preliminary key pointing requirements for NISAR are shown in Table 1.

Knowledge Reconstruction	Short-Term (3 seconds) Stability	Repeat-Pass Pointing Accuracy
60 mdeg/axis 1-σ	10 mdeg/axis 1-σ	53.6 mdeg/axis 1-σ

Table 1 – NISAR Pointing Requirements

To achieve these levels of performance, the spacecraft would need to meet pointing budget allocations as specified below in Table 2.

Error Type	**Error Source**	**Error in deg**
Knowledge Error	Star Sensor Accuracy (Nominal config)	0.003
	Thermal Distortion	0.01
	P/L to Star Sensor Alignment	0.01
	RSS of above	0.015
Reference Error	Orbit Source	0.005
Control Accuracy		**0.02**

Table 2 – Spacecraft Pointing Budget

Power Systems

In considering the design for the Power System, the spacecraft must be able to support the load when both payloads are operated simultaneously. The maximum specified duration for this occurrence would be 8.5 minutes. This may also be occurring during downlink time, and the other factor of spacecraft bus systems must also be included. This results in a total load of 5952 Watts, before margin, which increases to 8214 Watts with margin.

The solar arrays and battery together would produce 8533 Watts, which is sufficient to meet the demands from the payloads.

The solar array design for NISAR would use triple junction cells, with efficiency greater than 27%. The total array area would be 23.22 m^2. The battery design would use Li-Ion chemistry and is 180A-Hrs, in a 4P-16S configuration.

There are 64 cells in total for the battery, which is arranged as two separate modules.

Baseband Data Handling System

The Baseband Data Handling system is a state of the art high bit rate data handling system designed and realized by ISRO. The data handling system is configured as Main and Redundant.

The Solid State Recorder provided for L-Band radar payload will be shared for S-Band payload data recording also. The data handling system is configured to handle data collected by simultaneous operation of both L&S Band radar payloads for a duration of 10 minutes.

The S-Band radar payload operates at 3.2 GHz with PRF ranges from 2200 ± 200 Hz. Peak total data rate to BDH is 3.8 Gbps (Dual/Quad Pol). The L-Band radar payload's peak data rate is 2.4Gbps (Dual/Quad Pol).

The S-Band SAR data after getting formatted by BDH is stored in JPL SSR. The L-Band data get stored in SSR directly without ISRO's data handling system.

The heritage device used by ISRO for other spacecraft; Aeroflex UT54LVDS217/218 Serializer and Deserializer will have to work at its operating limits without any margin if used for data handling of NISAR and hence the data handling system configuration has been modified to employ very high speed Texas Instruments TLK2711 SerDes device. This device will use only 4 LVDS wire between Payload and BDH to transfer entire ~4Gbps rate data. This reduces the requirement of discrete harnesses by more than 75% of conventional design. The operating frequency of this device is between 80 MHz to 125 MHz. Formatting of data at this high speed and maintaining a throughput of 1.28 Gbps is one of the critical challenges ISRO would be working on in NISAR mission.

The BDH system is designed to take care of failure of one of the transmitters (two carriers are used), the data can still be transmitted using the other transmitter taking longer time for downlink.

CCSDS AOS Downlink formatter will support playback of recorded data independent of their record format.

4. Engineering Payload Challenges

Engineering Payload Overview

The Engineering Payload System (EPS) to be provided by JPL augments the spacecraft capabilities in order to meet mission objectives for the operations of the science payload (L-Band and S-Band instruments). The EPS consists of a payload data subsystem (PDS), a high-capacity/high-speed solid-state recorder (SSR), an advanced GPS Receiver Payload (GPSP), a high-rate Ka-Band telecom subsystem (Payload Comm), and a power distribution unit (PDU). The PDS, Payload Comm, and PDU are mounted inside the spacecraft bus, while the SSR and GPSP are mounted on the radar instrument structure (RIS).

Downlink Architecture

For NISAR, the quality of the measurements would improve by the square of the number of observations. In practical terms, this means more data leads to better science. The preliminary mission requirement for NISAR is to return 24 Terabits of data per day.

The two main telecommunication architectures for missions in low-Earth orbit (LEO) are relay via a space-to-space link or direct-to-Earth (DTE) communication. For relay, the NASA Tracking and Data Relay Satellite System (TDRSS) was considered. And for DTE, the options include a global network of ground stations, similar to the SafetyNet approach proposed for the JPSS program, optical communication terminals and the traditional use of high-latitude ground stations.

The TDRSS option offers the unique combination of high rate capability, paired with extended view periods, which allows for a very large downlink data volume capability. However, the downside of using TDRSS is the associated hardware that would be needed, namely a meter-size high gain antenna and gimbal system, combined with a boom for more flexible range of motion. Additionally, a high-power amplifier would be required for closing the link at a range of 40,000 km.

The option of having a globally distributed network of ground antennas does provide the opportunity for frequent downlink of data, however, interfacing with multiple locations worldwide would add complexity to the ground system design. All data would need to be routed back to JPL for science processing, and establishing links to multiple locations would increase the cost.

The high bandwidth capability of optical communication systems is attractive, but given the limited number of ground terminals, only a few downlink opportunities exists per day, further complicating the data storage needs of the mission.

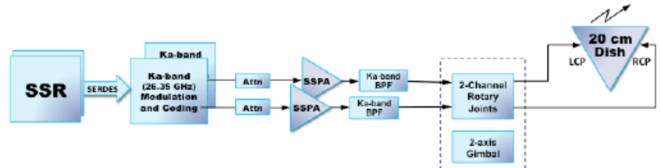

Figure 3 – Payload Comm System Configuration

Instead, NISAR proposes to use Ka-Band (25.5 – 27 GHz) for downlinking its vast quantities of data. The Payload Comm system configuration, shown in Figure 3, consists of two independent strings of hardware, sharing a common 20-cm high gain antenna. Due to the relatively short distance between the spacecraft and the ground, only a 4-Watt solid-state power amplifier (SSPA) is needed to ensure a robust link margin.

By operating both hardware strings simultaneously, NISAR could downlink data at an aggregate rate of up to 4 Gbps. With such a high rate, only a subset of the overflights for a given ground station are required to meet mission data volume requirements.

The development of the NISAR Ka-Band transmitter is led by JPL and would be the first operational use of gigabit-class downlink rates on an Earth Science mission.

Data Storage Architecture

The NISAR mission and L-Band instrument are designed to achieve global coverage twice, once on the ascending pass and once on the descending pass of the orbit, over the 12-day orbit cycle. Additionally, at the higher latitudes where there is more overlap of the orbits, targets are observed more often. Altogether, this results in an observational duty cycle ranging from 30-70% of the orbit. Figure 4 shows the typical amount of data produced over a 50-orbit time period.

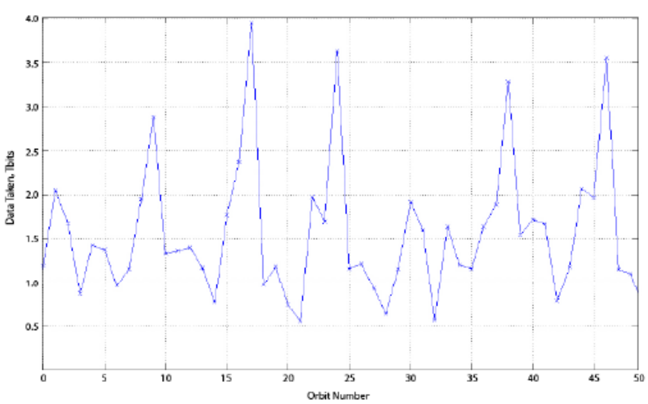

Figure 4 – NISAR Data Collected per Orbit

On average, the proposed NISAR mission would produce 2 Terabits (Tb) per orbit, with a peak closer to 4 Tb. When considering different timing scenarios for when downlink and peak data collection orbits occur, the required capacity can easily be doubled the values shown. Therefore, the NISAR mission would require an SSR with close to 10 Tb of capacity.

This level of capacity is a challenge for the Dynamic Random Access Memory (DRAM) technology presently used in onboard data storage systems. For a DRAM-based system, the amount of power required to support such a large capacity would be in the range of 200-300 Watts, since the memory chips are considered volatile. Also, the physical size of DRAM components are relatively large, which drives the packaging volume, and thereby the mass, which are equally unfavorable.

Beyond the capacity, there is also the challenge of how quickly data can be written to and read from the memory. As discussed earlier, data would be sent from the SSR to the Payload Comm system at a rate of up to 4.0 Gbps. However, this represents less than half of the rate that data would be written to the SSR. The combined input to the SSR from both radar payloads operating at the same time exceeds 9 Gbps per second. This is another limitation that prevents the adoption of DRAM technology for the SSR.

NISAR is planning to baseline the use of a NAND Flash memory-based storage system for the SSR. In addition to meeting the capacity and speed requirements of the mission, Flash technology offers reduced power consumption levels and mass. For a 10 Tb, Flash-based SSR, the expected power level is 125 Watts and the mass would be less than 25 kg.

Payload-to-Spacecraft Interface

Interestingly, one of the key challenges in the development of the Engineering Payload is to understand the different interfaces to the ISRO I3K spacecraft. Some elements of the Engineering Payload are mounted on the radar instrument structure, such as the SSR and GPSP, and others are mounted within the spacecraft bus structure, such as the PDS, PDU, and Payload Comm system. For items within the bus, the interface is mostly limited to mounting and thermal interfaces, but the PDS and PDU have additional interfaces.

The Payload Data Subsystem (PDS) serves as the *only* command and data interface between *all* of the Payload elements from JPL and the spacecraft. All commands sent to the spacecraft originate from ISRO ground stations and are processed by the spacecraft computer. Commands that are destined for the JPL elements are rerouted to the PDS. Once the PDS receives the transfer from the spacecraft computer, it behaves as if the information was transmitted directly from the ground.

One challenge in coming up with the design for the PDS stems from the fact the PDS resides on the spacecraft MIL-STB-1553B bus network. The PDS is the only element of JPL that is designated as a Remote Terminal (RT) on the I3K bus. This is what allows for the seamless transfer of commands to the PDS, and similarly the forwarding of onboard GPS solutions to the spacecraft computer. The need to understand the idiosyncrasies of the ISRO system is vital to the successful operation of the L-Band payload.

The other challenge for the PDS design is to make the interface with the spacecraft work using an existing design. In order to achieve a low-risk, low-cost implementation, the

PDS is a simplified version of the Command and Data Handling Subsystem to be flown on the SMAP mission. The simplifications come from the removal of functionality that is not needed by the Engineering Payload, such as Propulsion and Attitude Control.

Similar to how the PDS is the single command and data interface between the Engineering Payload and the spacecraft, the Power Distribution Subsystem (PDU) is the *main* power interface, as shown in Figure 5. (Though the PDS receives power directly from the spacecraft, it uses a design derived from the PDU.) The PDU is responsible for receiving the 70 volts from the spacecraft, and down converting it to the standard 28 volts commonly used by JPL hardware elements.

The challenge for the PDU design is to understand the characteristics of the I3K power system design and being sure it can efficiently meet the demands of the other Engineering Payload elements. The PDU must be able to handle a total output load of ~500 Watts at 28 volts, with an efficiency greater than 80%.

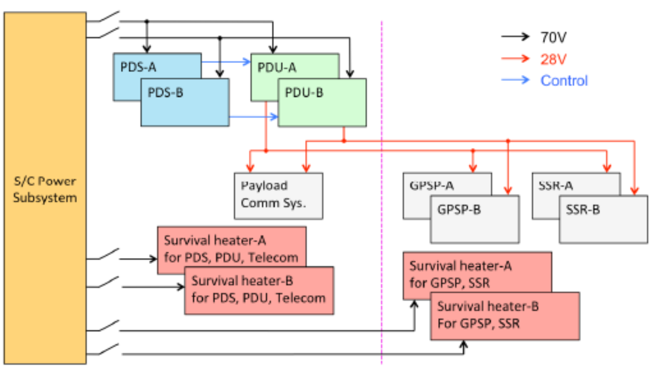

Figure 6 – PDU Architecture

The complete details of the interface for the PDS and PDU, and other Engineering Payload elements will be formally documented in the Flight System Interface Control Document (ICD). This document will have joint ownership and will be approved by the engineering teams, with concurrence from Project Management on both sides.

5. LAUNCH VEHICLE

Launch Vehicle Overview

As part of the collaboration NISAR is baselining the use of an ISRO supplied launch system for the mission. After many trade studies the Geosynchronous Satellite Launch Vehicle (GSLV) was selected as the launch system for the mission. In particular NISAR would use the Mk II version of GSLV which signifies the use of the ISRO's indigenously developed cryogenic stage as the third (upper) stage of the launch vehicle. The following sections provide the background and the status of the application of GSLV for NISAR.

Selection of GSLV Mk II for NISAR

The science and applications requirements of the NISAR mission concept necessitate an Observatory system (Payload + S/C Bus) design with significant mass and volume requirements. The well-proven Polar Satellite Launch Vehicle (PSLV) was found to be inadequate to meet the injected mass as well as the volume requirements of the Observatory design for the mission. Therefore, the developmental GSLV Mk II was chosen for the purpose. Its performance capability to the required mission orbit of 747 km sun-synchronous polar orbit is adequate with a comfortable mass margin at this stage of the mission development. It allows an Observatory mass up to 2600 kg to be injected into the required orbit. The CBE of the Observatory mass is about 2,000 kg thus allowing a 30% mass margin at this early stage of the design. Figure 6 provides a summary description of the GSLV launch system.

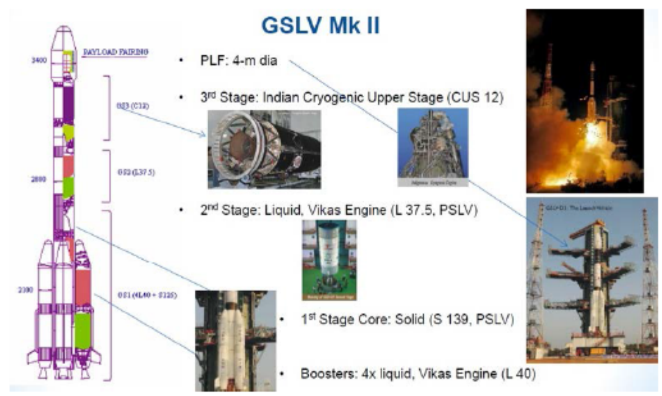

Figure 6 – GSLV Launch System

Launch Performance, injection accuracy, trajectory sequence and parameters

GSLV has been designed primarily to launch satellites into GTO/GSO missions. In the current manifest NISAR would be the first attempted launch into a polar sun-synchronous low earth orbit. Since, the Indian cryogenic upper stage does not possess an engine restart capability in orbit the mission cannot utilize a more efficient parking orbit ascent trajectory to the required final orbit. Instead, it uses a less efficient direct ascent trajectory to the final orbit. Nevertheless, the performance achieved is adequate for the mission, which is 2,600 kg to the required 747 km SSO.

Observatory Injection & Orbital Parameters

The orbital elements to be achieved are provided in Table 3. The orbital elements that are specified are at the first ascending node after separation.

Table 3 - Mission Orbit Targets

Parameter	Osculating orbit (1) elements
Semi-major axis	7114.653 km
Eccentricity	0.001255

Inclination	98.404°
Argument of Perigee	67.560°
Mean Anomaly	-67.427°
MLTAN	6:00 PM

ISRO/VSSC used these elements in their launch vehicle mission analysis to achieve the targeted orbit and provided the results as in Table 4. At the end of the ascent trajectory at LV/ Observatory separation the launch phase achieves the following injection parameters.

Table 4: Mission Orbit Achieved by LV

Orbit (km x km)	747.00 x 747.12
Semi-major axis (km)	7123.236
inclination (deg)	98.404
eccentricity	0.000008
Payload (kg)	2603
Injection Conditions	
H (km)	747.04
V (km/s)	7.4805
FPA (deg)	90
V.Az (deg)	188.82
Lat (deg)	-17.71
Long (deg)	79.13

Nominal Flight Sequence

Table 5 provides the GSLV launch sequence specific to the proposed NISAR launch. It is a direct ascent trajectory with the cryogenic stage single burn of 721 seconds to reach the required mission orbit.

Table 5 - Launch Sequence

Time from S139 ign.(s)	Events
-4.8	L40 ignition
0.0	S139 ignition
7.4	Pitching begins
148.9	L40 shut-off
149.5	GS2 ignition
151.1	GS1/GS2 sep.
156.9	IS 1/2M sep.
161.0	PLF jettisoning
292.5	GS2/CUS sep.
293.5	CUS start
1011.7	CUS Shut-off
1014.0	CUS burn out
1026.7*	Satellite Separation

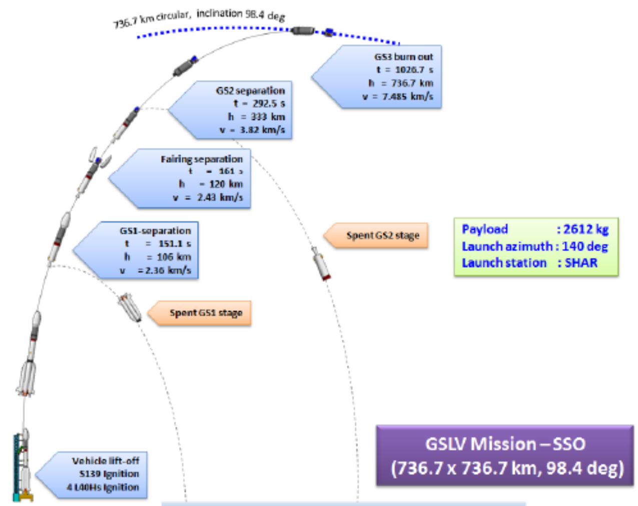

Figure 7 - GSLV Ascent Profile for NISAR mission Concept

Observatory Injection Accuracies (3σ)

The GSLV Mk II orbital injection accuracy is characterized by the following parameters.

- Semi-major axis: ± 20 km
- Inclination: ± 0.2 deg
- Eccentricity: < 0.003

Configuration accommodation inside the 4-m PLF

From volume perspective, only the existing 4-m payload fairing (PLF) heat shield was found to be applicable compared to the much used but smaller 3.4 PLF version. Attempts were made to fit the Observatory inside the 3.4-m PLF but only with significant and unacceptable loss in science return and mission objectives. Figure 8 provides a view of the inadequacy of the 3.4-m vs. the 4-m PLF for the current Observatory design.

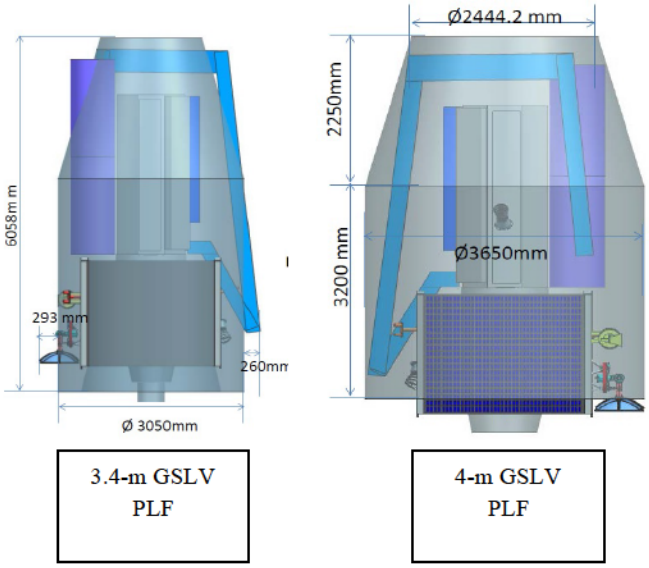

Figure 8 - GSLV Payload Fairing Comparison

Mass, CG and Load constraints

It has been a challenge for the NISAR unique Observatory stowed architecture configuration to satisfy the GSLV CG constraints. A major effort is underway to reconfigure to satisfy the following constraint for a 2,600 kg Observatory mass. This accommodation effort is tricky in order to satisfy the payload layout, cabling and accompanying thermal issues. Moreover, ISRO has never launched such a high configuration payload protruding into the conical section of the GSLV fairing. To maintain positive cg margin the project has decided to keep it within 2-m from the separation plane for the 2600 kg mass.

Table 6: GSLV Longitudinal CG Constraints

Observatory Mass, kg	Allowable longitudinal CG from Separation Plane, m
2000	3.1
2100	2.9
2200	2.7
2300	2.6
2400	2.4
2500	2.3
2600	2.2

The lateral CG constraints is +/- 10 mm from the longitudinal axis of the launch vehicle

The stiffness requirements imposed on the Observatory by GSLV are the fundamental frequencies that it should satisfy as below:

Longitudinal	> 40 Hz
Lateral	>12 Hz

Table 7: GSLV Stiffness Requirements

High level LV requirements for the mission

NISAR Observatory is a high value payload system both in terms of cost and science/ application value for the joint collaboration. Currently, due to its less favorable flight record, NASA considers GSLV a high-risk launch vehicle for the mission. In order to ensure mission success the JPL/NASA and ISRO together have evolved the following GSLV success criteria for acceptance of the use of GSLV Mark-II for the proposed NISAR mission.

1. A minimum of three successful GSLV Mark-II launches between 2014 and 2020 prior to the NISAR launch (including the January 2014 launch).

2. A successful GSLV Mark-II launch just prior to the NISAR launch.

3. Two consecutive successful GSLV Mark-II launches demonstrated prior to the NISAR launch (This could include the January 2014 launch).

4. At least one more successful 4-m fairing GSLV Mark-II launch between 2014 and 2020, prior to NISAR launch (Note that a 4-m fairing was successfully deployed in April 2010).

5. The latest 4-m fairing GSLV Mark-II launch prior to the NISAR launch must be successful.

These criteria have been incorporated in the NASA-ISRO Implementation Arrangement (IA) and will be levied as Level 2 requirements in the joint project requirements document.

With the next successful launch in 2015 criteria # 3 could be satisfied. One more successful 4-m fairing launch could satisfy criteria # 4 and # 5.

Overall, GSLV Mk II is a launch system that satisfies the preliminary NISAR mission requirements contingent upon future successful launches prior to NISAR to satisfy NASA launch success criteria above. ISRO is confident that with the engineering review process in place GSLV will achieve the required success criteria before NISAR launch.

6. SUMMARY

The proposed NISAR mission concept would be undoubtedly a very challenging but scientifically rewarding collaboration between the United States and India. This paper has touched upon some of the high level challenges in trying to accommodate the technically demanding needs from both the NASA and ISRO payloads. But given the resources available between the two agencies these challenges will be addressed by both the technical teams in the coming years. By utilizing the experience gained from the successful collaboration on Chandrayaan-1/Moon Mineralogy Mapper (M3) and by applying the best practices from each organization, these technical challenges will be overcome in due course. NISAR could serve as the flagship mission that leads to new directions for future international collaborations.

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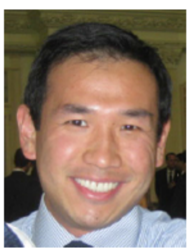
References

[1] Rosen, P. A., Hensley, S, Joughin I. R., Li, F. K., Madsen, S. N., Rodriquez, E. and Goldstein, R. M., "Synthetic Aperture Radar Interferometry," Proc. IEEE, v. 88, pp. 333—382 (2000)

[2] Rosen, P. A., Kim, Y., Hensley, S., Shaffer, S., Veilleux, L., Hoffman, J., Chuang, C.-L., Chakraborty, M., Sagi, R., Satish, R., Putrevu, D., and Bhan R., "An L- and S-band SAR Mission Concept for Earth Science and Applications," Proc EUSAR 2014, <https://www.vde-verlag.de/buecher/ivz/ivz3607.pdf> (2014)

Biography



Peter Xaypraseuth *is currently serving as the NISAR Flight System, Systems Engineering Lead and is responsible for overseeing the design of the Engineering Payload and the interfaces to the ISRO spacecraft.*

Peter received a B.S. in Aerospace Engineering from California State Polytechnic University, Pomona in 2000. He has been with JPL for more than 15 years, with most of that time spent on the Mars Reconnaissance Orbiter mission, where he had various systems engineering roles throughout Development and into Operations. He has also worked on the Dawn mission as a Systems Engineer responsible for developing contingency plans and also the GRAIL mission where he served as the lead Mission Engineer.

Alok Chatterjee *is currently the NISAR Mission Interface Manager and Launch System Engineer. He is responsible for managing the technical and management interface with ISRO as well as providing launch system engineering support for the mission.*

Alok received his B.Tech (Hons) degree in Aerospace Engineering from IIT Kharagpur, India in 1973 and MS in Aerospace Engineering from Iowa State University, USA in 1985. He also completed his EMBA at the Peter Drucker Management Center at Claremont Graduate University, California. Prior to joining JPL he worked at the ISRO/VSSC center between1973-1982 on launch vehicle design. After joining JPL in 1985 Alok has been a mission design engineer for the Galileo, Cassini and GRAIL deep space missions. He was the Project System Engineer for the Moon Mineralogy Mapper (M3)/Chandrayaan-1 collaboration mission with ISRO launched in 2008.

R.Satish *is currently the lead for Flight Systems and Project System Engineering of NISAR Spacecraft Elements responsible for the design of spacecraft systems and project system engineering aspects of the project.*

Satish is a mechanical engineer by profession and joined ISRO Satellite Centre, Bangalore, India in 1987. Worked in Environmental Test Facilities till 2005 responsible for design and development of several indigenous environmental test facilities and moved to Programme Management Office of Indian Remote Sensing Satellites. Since then, he has worked as Dy. Project Manager(Mech.Sys) for Cartosat 2 & 2A, Project Manager(Mech.Sys) for ISRO's first lunar project Chanddrayaan-1 and as Deputy Project Director of India's first interplanetary mission, Mars Orbiter Mission launched in November 2013 and inserted into Martian orbit recently on 24th September 2014 carrying out various system engineering lead roles throughout development and operations .

Presently he is also working as Mechanical Systems lead for ISRO's Scatsat-1(with Scatterometer payload) which is scheduled to be launched in the year 2015.